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Devonian Tully Limestone in Pennsylvania and Comparison to Type Tully Limestone in New York

Philip H. Heckel

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Devonian Tully Limestone in Pennsylvania and Comparison to Type Tully Limestone in New York

by Philip H. Heckel

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PREFACE

This report gives the results of a study of several exposures of the Tully Limestone in central Pennsylvania. The Tully Limestone consists of alternating layers of shaly limestone and shale in a sequence from 6 to over 200 feet thick in different areas. This study was undertaken to determine the exact nature of this rock sequence in Pennsylvania and to compare it to the nature of the Tully Limestone in New York where it was named and where it is better known.

In this study, the physical nature and general chemical composition of various rock layers in the Tully Limestone were described at different localities in Pennsylvania, and changes in these attributes from place to place were determined. Fossils occurring in different levels of the rock sequence were identified and used to show correlation within parts of the Tully sequence in Pennsylvania and also to suggest correlation to the established lower and upper Tully sequence exposed in New York.

This report should be of use to oil geologists, industries that utilize rock and stone, paleontologists, and general geologists. Oil geologists use the Tully Limestone as a distinctive subsurface marker unit in wells drilled for oil and gas in northern and western Pennsylvania and southern New York. Persons in rock and stone industries would be interested in the physical characteristics of the formation, such as variations in thickness, proportion of limestone to shale in the sequence, and gross chemical composition of these rocks. Knowledge of these attributes allows determination if the formation or parts of it might be useful as raw material for various industrial purposes. It is important to know that although the Tully is basically a limestone, it is composed of about one-half shale in Pennsylvania; furthermore, the limestone layers are impure, that is, they contain a large amount of fine-grained, noncarbonate material which may render the rock unfit for certain purposes, but perhaps favorable for others. Paleontologists are interested in the succession of fossil assemblages in layered rocks and how they compare in different parts of the country. General geologists are interested in the regional changes in nature of the formation and how this bears on the history of deposition of the rock.

The author concludes that the Tully Limestone is much shalier in Pennsylvania than in New York because the source of shale material was to the east and southeast near the Pennsylvania exposures. The source of limestone material was to the north and thus nearer to the New York exposures. Lime and shale sediments were deposited from these different sources in the sea that covered Pennsylvania and New York over 300 million years ago to form the distinct regional pattern of the Tully Limestone that is exposed today.

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DEVONIAN TULLY LIMESTONE IN PENNSYLVANIA AND COMPARISON TO TYPE TULLY LIMESTONE IN NEW YORK

by

P. H. Heckel*

ABSTRACT

In contrast to thick-bedded pure calcilutite dominant in New York, outcropping Tully Limestone in central Pennsylvania consists of shaly calcilutite, appearing both as knobbly and platy facies in the field, and calcareous shale. The Tully grades eastward in Pennsylvania to noncalcareous shale and extends southward as a tongue of calcareous shale into West Virginia. In west-central Pennsylvania a dominantly brachiopod fauna in the base of the Tully is succeeded upward by a more diverse assemblage which occurs in this position throughout most of the state. This faunal succession correlates well with that typical of the lower and upper members in New York.

Tully calcilutite contains whole, unabraded skeletal material with roughly similar biological composition in both states. Pennsylvania calcilutite, however, contains a much greater admixture of acid-insoluble terrigenous mud and is intercalated with much more calcareous shale than that occurring in New York. Because Tully carbonate mud was probably allochthonous, its origin must have been north of the New York outcrop. Thus Tully deposition occurred in a quiet sea into which the northern carbonate source and eastern terrigenous clastic source supplied fine sediments of different chemical composition to produce a pure calcilutite in New York grading eastward and southward into Pennsylvania to shaly calcilutite, calcareous shale, and ultimately noncalcareous shale.

INTRODUCTION

The Tully Limestone has been well known in New York since named and first described by Vanuxem in 1838 and 1842 near the village of Tully. It was not recognized definitely in Pennsylvania, however, until the mapping of Butts in 1918, and was described adequately only much later by Willard in 1934 and 1937. Before this time, Grabau (1917) discussed facies relations of the Tully Limestone and adjacent formations in New York. He postulated a northern carbonate sediment source for the Tully, and based his conclusion partly upon its supposed absence in Pennsylvania. In the course of recent detailed investigation of the Tully Limestone in New York, I have studied several exposures of the Tully in Pennsylvania in order to compare its lithologic nature with that in New York and to establish general southward trends in composition from New York. The results of these studies hopefully clarify some of Willard's observations concerning the Tully in Pennsylvania. More importantly they establish a significant directional trend in the composition of the Tully which relates to sediment source, and they show that Grabau's main conclusion concerning the origin of the Tully is reasonable in spite of his limited data.

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* Kansas Geological Survey, Lawrence, Kansas; publication authorized by the Director, Kansas Geological Survey.

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TULLY LIMESTONE IN NEW YORK

The Tully Limestone crops out for 100 miles across central New York (Figure 1). It is a thin sequence of carbonate rocks, not over 40 feet thick, which disconformably overlies several hundred feet of Middle Devonian Hamilton Group shale and sandstone, and conformably underlies several thousand feet of Upper Devonian shale, sandstone, and red beds. Recent work by Heckel (1966) shows that the Tully Limestone in New York is readily divisible into two members (Figure 2). The lower member is 3 to 21 feet predominantly of calcilutite which grades eastward into calcareous quartz sandstone. The upper member is 5 to 26 feet also predominantly of calcilutite which grades eastward into quartz siltstone and sandstone. In the central region of outcrop near Borodino the upper Tully contains a complex, at least 1,200 feet long, 300 feet wide and 30 feet thick, of calcilutite mounds and associated facies (Heckel, 1967). Both members are absent due to nondeposition westward where

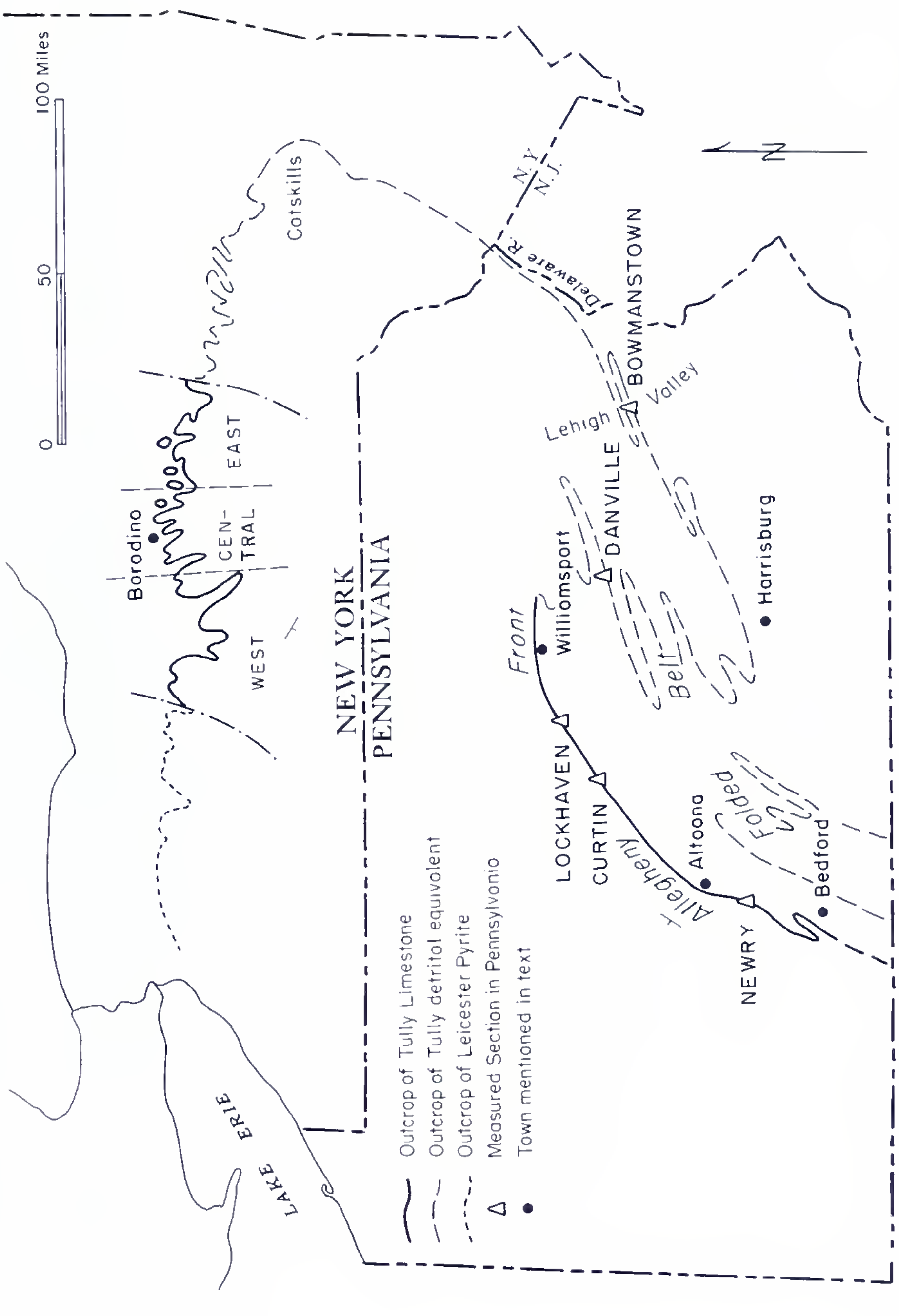

Figure 1. Outcrop map of Tully Limestone, detrital equivalents, and Leicester Pyrite in New York and Pennsylvania. Geographic regions of New York outcrop correspond to those in Figure 2, and Tables 2 and 3.

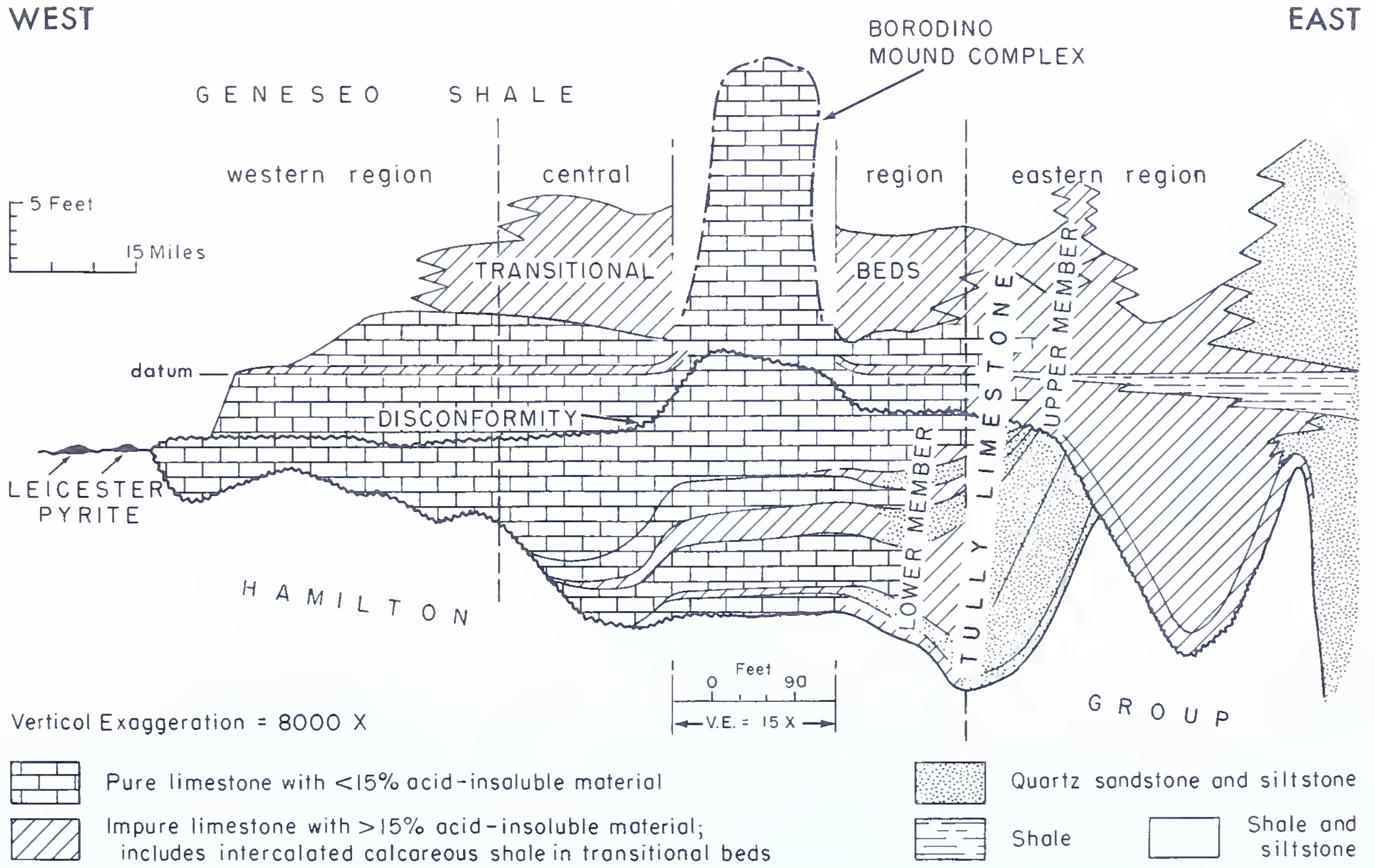

Figure 2. Simplified cross section of Tully Limestone in New York showing relations of members and transitional beds. Cross section based on over 70 measured sections (Heckel, 1966). Subdivisions within members are beds that served as basis for detailed correlation within formation. Vertical lines separate three outcrop regions shown in Figure 1 for which percentage insoluble residue and related data are averaged in Tables 2 and 3.

their position is occupied by the lenticular Leicester Pyrite. Separating the two members of the Tully is an intraformational disconformity that truncates the lower member eastward. The upper member grades upward into black fissile Geneseo Shale through transitional beds of up to 10 feet of alternating unfossiliferous shaly calcilutite and dark calcareous shale.

The presently recognized lower member corresponds approximately to the "Apulia" and "Tinker Falls" Members of Cooper and Williams (1935); the upper member corresponds approximately to their "West Brook" Member and includes the "Apulia" east of the truncation of the lower member.

TULLY LIMESTONE IN PENNSYLVANIA

For a long time the Tully Limestone has been known as a distinctive marker zone (Fettke, 1933) in the subsurface of southern New York and northern Pennsylvania between the two regions of outcrop. First report of definite exposed Tully Limestone in Pennsylvania was made by Butts (1918) who found, near Altoona, 1 foot of limestone containing *Chonetes aurora* (Hall), a brachiopod which in New York is restricted to the Tully Limestone and its equivalents. Willard (1934, 1937, 1939) discovered most of the outcropping Tully Limestone in Pennsylvania, summarized its distribution, nature, stratigraphic relations and fossil content, and made note of the eastern detrital equivalent. More recently, Jones and Cate (1957) summarized lithologic data for the Tully in Pennsylvania in an isopach and facies map.

From the New York outcrop, the Tully Limestone dips southward beneath a great thickness of younger detrital rocks and is brought up by Appalachian folding in central Pennsylvania (Figure 1). It is present from Bedford northeastward past Williamsport along the great arc of the Allegheny Front. In Pennsylvania the Tully Limestone consists predominantly of shaly calcilutite and calcareous shale. A remarkable aspect of the Tully in central Pennsylvania is its great thickness. At Larry's Creek, west of Williamsport, it exceeds 240 feet; the base is not exposed, yet the Tully Limestone is at least seven times as thick as its thickest complete exposure in New York.

The Tully Limestone in Pennsylvania overlies siltstone and shale of the Mahantango Formation which is the upper part of the Hamilton Group. The Tully is overlain by black fissile Burket Shale, the lithologic equivalent of the Geneseo.

Southwestward along the Allegheny Front the Tully Limestone grades into calcareous shale. J. M. Dennison (personal communications, 1965, 1966) and Hasson (1966) traced the Tully horizon, by means of its more calcareous lithology and characteristic fossils, into the thick Devonian shale sequence of eastern West Virginia. Farther southward it either grades into noncalcareous shale or is represented by a surface of nondeposition.

Southeast of the Allegheny Front in the "Appalachian Folded Belt," the Tully grades into a detrital equivalent of shale which becomes increasingly sandy to the southeast (Ellison, 1965). The stratigraphic interval of the Tully in this region was known previously only from isolated reports of *Hypothyridina*, *Chonetes aurora*, and *Metriophyllum* from limestone nodules in shale (Willard, 1939) in exposures northwest of Harrisburg. More recently, Ellison (1965) has identified *Emmanuella pennsylvanica* Willard and *Echinocoelia* at other localities in the same region, and D. M. Hoskins (written communication, 1966) has stated that the Tully interval is represented throughout most of the folded belt by calcareous shale less than 5 feet thick.

East of the Allegheny Front, shaly limestone layers persist to Danville. Most of the exposure at Danville, however, is calcareous shale which a short distance farther east comprises the entire interval and carries the characteristic Tully fauna to the region of the Delaware River. In the Lehigh Valley and east, Skinner (1948) and Stevenson and Skinner (1949) report faunal differentiation in the Tully detrital equivalent similar to that determined in eastern New York by Cooper and Williams (1935). The easternmost known diagnostic Tully fossils in Pennsylvania occur near the Delaware River in gray sandstone which presumably passes northeastward into red beds of the Catskill facies in New York.

DESCRIPTION OF SECTIONS OF TULLY LIMESTONE AND EQUIVALENT IN PENNSYLVANIA

In order to better relate the Tully in Pennsylvania to recent findings in New York (Heckel, 1965, 1966), five representative sections of Pennsylvania Tully and its equivalents were visited, sampled and correlated (Figure 3). The sections are described from southwest to northeast.

NEWRY

The Tully Limestone at Newry, a short distance south of Altoona, is 6 feet thick. The lower 2.5 feet consists of shaly, wavy medium-bedded limestone that in the lower foot resembles large 6-inch limestone nodules in a gray-shale matrix. These nodules are impure calcilutite which con-

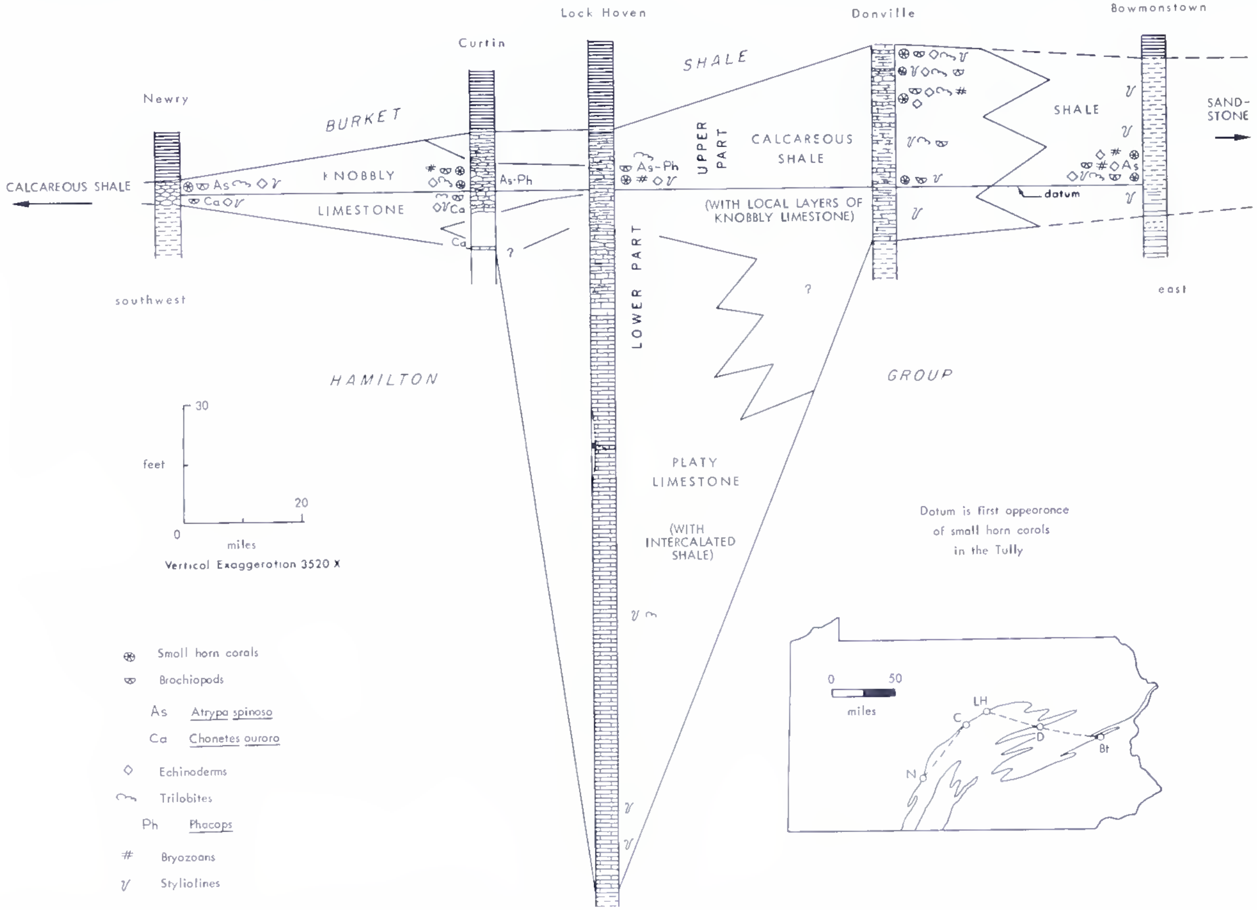

Figure 3. Correlation of five measured sections of Tully Limestone and eastern detrital equivalent in Pennsylvania. Facies relations between limestone and shale types within Tully shown by zigzag lines. Possible facies relations between Tully and overlying black Burket Shale and underlying Hamilton Group shales and siltstones are not shown. Exact locations of measured sections given in Appendix A.

tains about 25 percent fine quartz silt, clay and pyrite, and the associated shale is similar to the underlying calcareous Hamilton. The fauna of the lower part of the Tully is dominated by the brachiopods *Chonetes aurora* (Hall), *Emmanuella pennsylvanica* Willard, and *Echinocoelia ambocoeloides* Cooper and Williams.

The upper 3.5 feet of Tully Limestone at Newry consists of shaly, wavy thin-bedded limestone. Insoluble residue in these skeletal calcilutites ranges from 35 to 60 percent. Although the upper part seems to be gradational with the underlying portion of the Tully, it contains at lower levels many intraclasts up to 0.5 inch in diameter (Plate 1, Figure 6). The top is an abrupt but transitional contact with the fissile black shale of the Burket. The fauna of the upper part of the Tully is dominated by small horn corals *Syringaxon, Nalivkinella* and *Metriophyllum,* styliolines (small, exceedingly thin-walled, cone-shaped fossils about 1 to 2 mm long), pelmatozoans, trilobites and auloporid corals. Brachiopods include *Productella, Schuchertella, Leptaena,* and *Atrypa spinosa* Hall.

CURTIN

The Tully Limestone at Curtin is between 30 and 40 feet thick. The lower 10 feet are mostly covered. The next 20 feet consist of thin-bedded shaly limestone to shale in layers up to 2 feet thick interbedded with several ledges of limestone 0.2 to 1 foot thick. Although the limestones are impure calcilutite averaging 25 percent in insoluble content, they stand out in contrast to the reentrant shales of which some contain 85 percent insoluble material. The contact with the Burket is poorly exposed.

Styliolines and pelmatozoan pieces occur throughout the Tully at Curtin. *Chonetes aurora* was found in the lower part of the section, and *Emmanuella, Echinocoelia,* and *Hypothyridina* were noted by Willard (1937). In the middle to upper part, trilobites, auloporid corals, and small rugose corals of the same three genera as at Newry, occur with the brachiopods *Ambocoelia, Productella,* and *Atrypa spinosa.* In the upper middle is a diverse fauna containing fenestellid, rhomboporid, sulcoreteporid, and fistuliporid bryozoans, and small spiriferids in addition to the other elements. The abundance of *Atrypa spinosa* suggests the *Atrypa-Phacops* zone of Willard (1937, p. 1244). Styliolines are rare in this zone just as they are in the richly fossiliferous *Elytha fimbriata* zone of the upper Tully in New York.

LOCK HAVEN

At Lock Haven, the Tully Limestone attains a thickness of about 200 feet. The lower 150 to 175 feet comprise a regular, evenly thin-bedded alternation of 1.5- to 2-inch limestone beds interbedded with similar thicknesses of calcareous shale (Plate 1, Figure 1). Because the limestones weather lighter gray than the shaly interbeds, a regularly banded or ribboned appearance is imparted to the outcrop. The limestone beds are all calcilutite with 15 percent to 25 percent residue and the interbedded shales range from 35 percent to 75 percent insoluble residue. The sequence rests with rather sharp contact upon platy unfossiliferous Hamilton shale. Approximately the upper one-fifth of the Tully at Lock Haven consists of calcareous shale with several thicker layers of shaly limestone (Plate 1, Figure 2) like those at Curtin. This grades to both the alternation of limestone and shale below and the black Burket Shale above.

Most of the lower limestone and interbedded shale is barren of fossils; only rare styliolines and a trilobite and echinoderm fragment were seen. In both the thicker limestone and shale beds at the top of the Tully is the diverse fauna containing the *Atrypa-Phacops* zone that Willard correlates to Curtin. Several types of small horn corals, other trilobites and brachiopods, particularly spiriferids, also occur in this fauna.

Lack of diagnostic fossils and extraordinary thickness of the lower sequence of interbedded limestone and calcareous shale at Lock Haven raises the question as to whether it is equivalent to the lower part of the Tully elsewhere in Pennsylvania or may perhaps be equivalent to the upper part of the Hamilton Group. Lithologically, it is undeniably more closely related to the Tully and thus is included as part of a rock-stratigraphic unit in the Tully Limestone. The *Sulcoretepora* zone, containing the brachiopod *Pustulatia,* is the highest diagnostic faunal zone in the Hamilton in Pennsylvania (Ellison, 1965). It was not searched for in the Lock Haven exposure, but if it were found in the shales beneath the limestone sequence, it would suggest that most, if not all, the limestone is probably equivalent to the Tully elsewhere.

DANVILLE

The Tully Limestone just south of Danville is 47 feet thick. The lower 15 feet consists of calcareous shale of which a typical sample contains 57 percent insoluble material. This rests on more clayey and chippy Hamilton shale with an indistinct, perhaps gradational, contact. The upper 32 feet of Tully at Danville consists of calcareous shale with irregularly spaced, hard, yellowish-weathering limestone beds from 0.2 to 1 foot in thickness. The shale contains up to 85 percent insoluble material even in fossiliferous zones. The limestones are impure and range from 30 percent to 50 percent in insoluble content. Gray-weathering patches of purer limestone impart a nodular appearance to these layers which resemble the knobbly-bedded, shaly to silty upper Tully in east-central New York. The top of the Tully at Danville is not well exposed.

Only styliolines were seen in the lower shale. In the upper shale and limestone, all three genera of small horn corals are common at several levels, and pelmatozoan pieces, trilobites, auloporids, and styliolines occur throughout. Fenestellid and rhomboporid bryozoans were seen at one level. Brachiopods include *Elytha fimbriata* (Conrad), *Atrypa spinosa, Schuchertella, Ambocoelia, Echinocoelia,* several other spiriferids, and rare *Hypothyridina,* which caused Willard (1934, 1935a) to identify this as the first described Tully section in Pennsylvania.

BOWMANSTOWN

The Tully as a limestone does not persist to the east of Danville but the faunal zone characterizing the Tully is traced eastward into the detrital facies. Willard (1939, p. 225; 1957) states that limestone recurs in the Lehigh Valley just north of Bowmanstown where I have seen only noncalcareous, sheared, hard silty shale about 40 feet thick, carrying the diagnostic fauna. Four fresh samples from different parts of this section, including the most fossiliferous zone, range from 92 percent to 100 percent insoluble in acid. The lower contact is placed at a prominent parting over similar silty shale that contains Hamilton fossils. The upper contact is gradational to the darker and less resistant Burket Shale. Rare styliolines occur throughout the Tully equivalent, and a diverse and abundant fauna occurs in a 10-foot-thick zone just below the middle of the unit. This fauna consists of echinoderm pieces, trilobites, auloporid and small horn corals, fenestellid, sulcoreteporid, rhomboporid and fistuliporid bryozoans, and brachiopods, including *Atrypa spinosa* Hall, small spiriferids, a terebratulid and *Douvillina.*

LITHOLOGY OF THE TULLY

PREVIOUS OBSERVATIONS

Willard (1937, p. 1242-1244) recognized in the Tully Limestone of Pennsylvania two lithologically and faunally distinct facies or "phases" which he termed "platy" and "massive." The "platy phase" is best developed in the vicinity of Lock Haven and Williamsport and characterizes the thicker sections of greater than 40 feet. It consists of light gray weathered, fine-grained limestone in 2-inch-thick layers separated by thin partings of black shale. Fossils occur in the upper part and consist mainly of corals, trilobites, and such brachiopods as *Atrypa spinosa, Elytha fimbriata,* and other spiriferids.

He states that the contrasting "massive phase" occurs along the Allegheny Front southwest of Lock Haven and characterizes the thinner Tully sections of which none exceed 10 feet. This "phase" consists principally of massive darker gray to brownish, hard, dense, fine-grained limestone and carries a fauna characterized by the brachiopods *Chonetes aurora, Emmanuella, Echinocoelia,* and *Hypothyridina.*

Willard feels that these two "phases" are contemporaneous because they seem to intergrade laterally in the exposure near Curtin where "platy phase" limestone is interbedded with the "massive" type. Faunal elements from both "phases" occur here. In addition, the 35-foot thickness of the Tully at this exposure is intermediate between the characteristic thickness for the two different "phases."

PRESENT OBSERVATIONS

In the Tully Limestone of Pennsylvania three facies now are recognized on the basis of field appearance rather than the two "phases" described by Willard. These three facies are: knobbly limestone, platy limestone, and calcareous shale. The first essentially replaces Willard's "massive phase" and the latter two can be discerned in his "platy phase."

The Tully Limestone at Newry in the region occupied by Willard's "massive phase" is actually shaly and wavy bedded or "knobbly," and is not massive like the Tully in western New York. Knobbly limestone is found also as interbeds in the Danville, Curtin, and top of the Lock Haven sections. All samples studied from this facies are shaly calcilutite containing from 23 percent to 59 percent insoluble material and 10 percent to 30 percent skeletal material. Finely crystalline limestone mentioned by Willard (1937, p. 1243) was not seen. The knobbly limestone facies of Pennsylvania most closely resembles the wavy, thin-bedded, shaly limestone of the upper member of the Tully in eastern New York.

The platy limestone facies is similar to that described by Willard as "platy phase" in the lower 150 feet (approximate) of the Lock Haven section. This evenly thin-bedded, rhythmic alternation of limestone and shale (Plate 1, Figure 1) comprises only the lower part of the thicker Tully sections in the Lock Haven-Williamsport region. Limestone layers of this facies consist of nearly unfossiliferous calcilutite containing 13 percent to 25 percent insoluble material and less than 5 percent skeletal material. The platy limestone facies has no close counterpart in appearance or thickness in the Tully Limestone of New York. It is included in the Tully as a rock-stratigraphic unit because it is limestone.

The calcareous shale facies consists of very thin-bedded, easily split shale containing from 60 percent to 85 percent insoluble material and makes up most of the remainder of those rocks designated by Willard as "platy phase." This facies is nonskeletal to skeletal calcilutite in which acid-insoluble, terrigenous mud is dominant. Calcareous shale separates knobbly limestone layers at Curtin, Lock Haven (Plate 1, Figure 2) and Danville. It comprises at least five-sixths of the section at Danville and replaces all limestone shortly eastward. Forming the eastern detrital Tully equivalent, this shale loses nearly all its carbonate content in the Lehigh Valley and grades eastward into sandstone. Calcareous shale in the Tully Limestone of central Pennsylvania closely resembles shale layers in the upper member of the Tully in east-central New York and in the transitional beds throughout the New York outcrop.

CONTACTS

In the Pennsylvania sections studied, the upper contact of the Tully Limestone is gradational with the overlying black Burket Shale as stated by Willard (1937). Likewise, the upper Tully throughout most of the New York outcrop is gradational with the overlying black Geneseo Shale. Transitional beds of intercalated unfossiliferous calcilutite and shale characteristic of the New York section, however, are lacking in Pennsylvania.

The contact of the Pennsylvania Tully with the underlying Hamilton shales and siltstones is not as distinct, partly because of the greater shaliness of the Tully and its resulting closer resemblance to the Hamilton. In places, bedding character of the Tully is different enough from the underlying shales such that the contact seems sharp in the field as Skinner (1948) has noted in eastern Pennsylvania where Tully-equivalent shale overlies Hamilton shale. Close inspection of the contact in central Pennsylvania does not reveal abruptness of change, nor evidence of disconformity or erosion that characterizes the base of the Tully in New York and which was postulated by Willard (1935b, 1937, 1939) in Pennsylvania. The Tully-equivalent shales in the "Folded Belt" of central Pennsylvania seem to lie conformably upon the Hamilton (D. M. Hoskins, written communication, 1966), and may be laterally gradational in places with the top of the Hamilton (Ellison, 1965).

FAUNA

Essentially two faunal assemblages are apparent in the Tully Limestone of Pennsylvania. These assemblages correspond roughly to those in the two members of the Tully in New York. Willard (1937) distinguished similar faunal differences between his two "phases" in observing that the "platy phase" faunally resembled the upper Tully ("West Brook") of New York, whereas the "massive phase" carried fossils found more commonly in the lower Tully ("Apulia").

LOWER ASSEMBLAGE

In the present study, one assemblage was found in the southwestern part of the Pennsylvania outcrop in the lower 2.5 feet at Newry, in fewer numbers in the lower beds at Curtin, and locally in shale in the "Folded Belt" (Ellison, 1965). It consists primarily of the brachiopods *Chonetes aurora* (Hall), *Emmanuella pennsylvanica* Willard, and *Echinocoelia ambocoeloides* Cooper and Williams, as well as pelmatozoan pieces and styliolines. This is Willard's "massive phase" fauna, and, in conjuction with *Hypothyridina venustula* (Hall) reported by him, resembles the fauna in the lower member of the Tully in New York. There are several regional differences, however, among the characteristic brachiopods which are the diagnostic members of the fauna: (1) the presence in Pennsylvania of the larger species of *Emmanuella*, *E. pennsylvanica* Willard, rather than *E. subumbona* (Hall) which is common in New York; (2) the common occurrence in Pennsylvania of *Echinocoelia* which is rare in the New York lower Tully but much more common in its eastern detrital equivalent (Laurens); and (3) the apparent absence or at least great scarcity in Pennsylvania of such distinctive New York lower Tully forms as *Leptostrophia tulliensis* H. S. Williams, *Atrypa* sp., *Schizophoria tulliensis* (Vanuxem), and *Schuchertella arctostriata* (Hall). A few other brachiopods as well as the former two of these genera are reported by Willard (1937, p. 1247-1248) from other "massive phase" sections of west-central Pennsylvania, but it is not known whether or not these occur in the lower part of the formation.

UPPER ASSEMBLAGE

The other faunal assemblage is much more widespread in the Pennsylvania Tully, occurring in the calcareous shale and knobbly limestone facies of the upper 3 to 35 feet of all the sections visited. This includes the upper 3.5 feet at Newry and presumably also other exposures of the "massive phase" from which Willard (1937) has listed fossils typical of this assemblage. The assemblage is characterized by the small horn corals *Metriophyllum, Nalivkinella,* and *Syringaxon,* auloporid corals, pelmatozoans, trilobites, styliolines, and the brachiopods *Atrypa spinosa* (Hall), *Elytha fimbriata* (Conrad), *Ambocoelia, Echinocoelia,* other spiriferids, *Tropidoleptus, Schuchertella, Leptaena,* and *Productella;* fistuliporid, fenestellid, sulcoreteporid and rhomboporid bryozoans occur locally. This assemblage is nearly identical to that carried by the upper member of the Tully Limestone in New York. Presence of the brachiopods and bryozoans suggests close affinities to the diverse *Elytha fimbriata* zone fauna of Cooper and Williams (1935). The bryozoans may occur only in a restricted zone in Pennsylvania, but the brachiopods seem more widely distributed throughout the vertical section than in New York.

ASSEMBLAGES IN EASTERN DETRITAL EQUIVALENT

Willard traced the upper assemblage eastward through the Tully equivalent shales to Bowmanstown. Skinner (1948) and Stevenson and Skinner (1949) have discovered more faunal assemblages in the increasingly sandy Tully detrital equivalent farther eastward in the region from the Lehigh Valley to the Delaware River. They correspond almost exactly in faunal composition and stratigraphic succession to the faunal zones of the eastern detrital Tully equivalents in east-central New York and were used to define members. In ascending order, they are: (1) a zone characterized by the brachiopod *Leiorhychus mesocostale* (Hall) and little else (Weissport Member*-New Lisbon of New York): (2) a zone characterized by the brachiopods *Echinocoelia* and *Hypothyridina,* the latter less common than in New York, (Brodhead Creek Member*-Laurens of New York); (3) a zone characterized by small corals, *Elytha fimbriata* (Conrad) and other brachiopods, and trilobites (Lehighton Member*-West Brook or upper Tully of New York). The latter is the zone observed at Bowmanstown.

CORRELATION

WITHIN PENNSYLVANIA

The datum in Figure 3 is the first appearance of small horn corals in the Tully Limestone and its eastern equivalent. Although it may be a diachronous line, it handily divides the Tully in Pennsylvania into two convenient faunal units corresponding in part to the lower, and throughout to the upper fossil assemblages. The major subdivision of the Tully Limestone in New York is based on an intraformational disconformity, but this also corresponds to the first appearance of small horn corals in any abundance in that region, and separates two different faunal assemblages. No such disconformity was detected in Pennsylvania, and intraclasts like those observed at Newry occur in the upper member away from the disconformity in New York. Willard's (1939) *Atrypa-Phacops* zone correlated between Curtin and Lock Haven is parallel to the datum of first appearance of horn corals, as are other faunal zones in New York.

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* The names Weissport, Brodhead Creek and Lehighton Members (Stevenson and Skinner, 1949) are not presently recognized by the Pennsylvania Geological Survey.

The upper part of the Pennsylvania Tully varies little in thickness and consists of knobbly limestone grading eastward to calcareous shale. The lower part, on the other hand, thins drastically away from the platy limestone facies in the vicinity of Lock Haven, and passes eastward into calcareous shale and southwestward to knobbly limestone carrying the lower faunal assemblage. It is possible that the platy limestone facies is older than any of the thinner sections of Tully, but no elements of the lower assemblage were found above it at Lock Haven. Probably, this facies was deposited relatively more rapidly.

The twofold vertical subdivision of the Pennsylvania Tully on faunal evidence necessitates further comment on the Curtin section where Willard described the lateral intergradation between his "platy" and "massive phases," and their respective faunas. *Chonetes aurora* was found by me only in two lower beds here, whereas the small corals, bryozoans, *Atrypa spinosa,* etc. were found only in the higher beds. Collections were not extensive enough to pinpoint the location of *Emmanuella, Echinocoelia* and *Hypothyridina* reported by Willard. The higher, coral-dominated faunal assemblage (of Willard's "platy phase") was found in the thicker ("massive") limestone layers as well as in the intervening shales. This is contrary to Willard's view of lateral gradation of the faunal assemblages. Furthermore, it is thicker calcareous shale beds like those higher in the Lockport section, and not the lower rhythmically interbedded platy limestone and shale, that represent Willard's "platy phase" in the supposed lateral gradation at Curtin.

BETWEEN PENNSYLVANIA AND NEW YORK

The same faunal succession that occurs in the Tully Limestone in New York is observed in the sections in west-central Pennsylvania. At Newry and Curtin, a predominantly brachiopod fauna typical of the New York lower Tully is succeeded by a coral-trilobite-brachiopod-bryozoan fauna typical of the upper Tully. This upper assemblage occurs in the upper part of the Tully throughout Pennsylvania and is traced into the eastern detrital equivalent where it overlies other faunal zones similar to those it overlies in the eastern detrital equivalent in New York. Lithologically as well as faunally, the upper part of the Tully Limestone in Pennsylvania resembles the shaly development of the upper member of the Tully in eastern New York.

The main departure from this pattern of similarity of the Tully between its two major regions of outcrop is in the lower part toward the east in both states. The thick, regular, alternating sequence of unfossiliferous platy limestone and calcareous shale at Lock Haven is unique, although the rock type and sparse fauna do resemble that of the transitional beds at the top of the Tully in New York. The sandy limestone and quartz sandstone of the lower member in New York are lithologically unlike any of the Pennsylvania Tully and carry a more diverse and abundant brachiopod fauna than does the lower part of the Tully in west-central Pennsylvania.

Nevertheless, the similarities suggest correlation of the lower and upper parts of the Pennsylvania Tully directly to the lower and upper members in New York. Until more detailed study is carried out in Pennsylvania, however, I hesitate to refer to the two faunal units separated by the datum in Figure 3 as members or entities of the same value of known lateral persistence as those recognized in New York.

PETROGRAPHY

Petrography of the Tully Limestone in Pennsylvania was studied by means of thin section and insoluble-residue analysis. Methods are delineated in Appendix B.

COMPOSITION AND FABRIC

All limestone observed in both facies from the Tully in Pennsylvania is impure calcilutite (Table 1). Variations in this rock type range from unfossiliferous or nonskeletal calcilutite (Plate 1, Figure 4) to fossiliferous or skeletal calcilutite (Plate 1, Figures 5-8). All Tully calcilutite is remarkably free of noticeable diagenetic alteration. Skeletal material is well preserved and for the most part unbroken and unabraded. The thin-shelled styliolines, however, are typically crushed in shalier rocks where more compaction has taken place (Plate 1, Figure 7). Burrowing is noticeable in the swirled pattern imparted by small stylioline pieces in skeletal calcilutite, but is marked only by local slight color differences in barren calcilutite. Intraclasts, or pebbles of calcilutite redeposited in a similar sediment, are distinguished from the matrix by differing fabric or amount of skeletal content (Plate 1, Figure 6). Except for local accumulations of small pellets inside closed shells and a few burrows, no other significant structures are apparent.

The lithologic variety of carbonates observed in New York, for instance calcarenitic, quartzose, and mound-associated facies, is not apparent in Pennsylvania. In order to achieve a more meaningful comparison of composition of the Tully between the two regions of outcrop, only samples from the calcilutite facies in New York were averaged for Table 1. Furthermore, the calcareous shale that comprises approximately one-half of the Tully in Pennsylvania was not thin sectioned and thus is not included for comparison in this table.

Table 1.—*Average percent constituent composition of Tully Limestone in Pennsylvania by facies and total, and in New York determined from point-count analysis of representative thin sections. All Pennsylvania samples studied are calcilutite; two knobbly facies thin sections are from lower part, three from upper part of formation. Values for New York represent only samples from calcilutite facies for better comparison. Appendix C gives raw data for Pennsylvania.*

	PENNSYLVANIA			NEW YORK
CONSTITUENT	*Knobbly facies (Newry, Curtin) 5 thin sections*	*Platy facies (Lock Haven) 3 thin sections*	*Total 8 thin sections*	*120 thin sections*
Corals	1.2	.....	0.8	0.8
Bryozoans	0.4	.....	0.3	0.2
Brachiopods	1.2	.....	0.8	1.6
Molluscs, ostracodes	.....	.....	.....	0.2
Trilobites	0.6	.....	0.4	1.1
Echinoderms	5.0	0.1	3.1	5.5
Styliolines	4.9	1.7	4.0	4.4
Unknown skeletal sand	3.3	2.3	2.9	2.1
Total Skeletal	16.6	4.1	12.3	15.9
Carbonate mud <.062 mm	49.1	77.0	59.5	67.2
Carbonate spar	0.5	0.2	0.4	1.1
Insoluble mud <.01 mm	31.9	14.4	25.3	10.9
Quartz, other detrital >0.1 mm	1.1	3.7	2.1	4.0
Other noncarbonate	0.7	0.7	0.7	0.9
	99.9	100.1	100.3	100.0

Differences exist between the calcilutites from the two facies in Pennsylvania. The knobbly facies (Plate 1, Figures 5-8) contains greater diversity of fauna and a four times greater abundance of skeletal material than the platy facies (Plate 1, Figure 4). Knobbly calcilutite also contains twice the amount of noncarbonate mud but less quartz of greater than .01 mm grain size than platy calcilutite.

A remarkable similarity exists in the average composition of all samples of Tully calcilutite between the two regions of outcrop despite the small number of samples analyzed from Pennsylvania. Relative amounts of the various skeletal grain types in knobbly calcilutite and nonskeletal material in platy calcilutite of Pennsylvania correspond well to their respective relative amounts in New York calcilutite.

The main difference between the two regions of outcrop is the greater abundance of noncarbonate (insoluble) mud in Pennsylvania.

This has important regional implications. Several smaller differences may also be significant on a regional scale. Brachiopods are much more common in the lower Tully in New York than at any place observed in Pennsylvania. Although quartz is disseminated throughout the Pennsylvanian samples and is common in the platy facies, it is nowhere as abundant as in the eastward gradation to sandstone of the lower member in New York.

INSOLUBLE RESIDUE

Insoluble-residue analysis, utilizing formic acid diluted 1:5, was carried out on 19 samples of Tully Limestone in Pennsylvania including the 8 for which thin sections were point counted. Average percent insoluble residue for limestone in the four measured sections is shown in Table 2 with average equivalent values for New York by major unit and geographic region for comparison.

All 14 samples of limestone analyzed from the Pennsylvania Tully average 33 percent insoluble material compared to 28 percent for the 8 samples point counted. This discrepancy is accounted for by the difficulty of thin sectioning shalier limestones. Because insoluble residue analysis encompassed a greater range of rock than point-count analysis in the Pennsylvania Tully, this type of data was used as a basis for further comparison of composition of the Tully in its two major regions of outcrop.

The nature of insoluble material is consistent throughout the Pennsylvania Tully and is similar to that in the upper member of the New

Table 2.—*Comparison of average amount of insoluble residue in limestone beds of Tully Limestone in New York and Pennsylvania. Numbers are percent material insoluble in 1:5 formic acid solution. Parentheses enclose number of samples averaged. Appendix D gives raw data for Pennsylvania.*

	NEW YORK		
	West	*Central*	*East*
Transitional beds	26 (4)	20 (22)	28 (3)
Upper Member*	9 (21)	7 (31)	22 (73)
Lower Member	8 (23)	11 (74)	51 (50)

PENNSYLVANIA			
Southwest		*Northeast*	
Newry	Curtin	Lock Haven	Danville
45 (4)	27 (3)	20 (4)	42 (3)

Average for all limestone analyzed in Pennsylvania Tully: 33 (14)

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*Exclusive of transitional beds

York Tully. All insoluble residues examined in the widely separated Pennsylvania sections consist of aggregates of argillaceous material and quartz silt typically less than .01 mm in diameter; larger quartz grains are subordinate in number and rarely exceed .06 mm in diameter. The upper Tully in New York contains argillaceous material and quartz silt that commonly does not exceed .06 mm in grain size. On the other hand, New York lower Tully of similar insoluble percentage commonly carries a greater relative amount of quartz sand much of which exceeds .10 mm in grain size.

Table 2 shows that, on the average, limestone in the Pennsylvania Tully contains more insoluble residue than any of the stratigraphic-geographic subdivisions of the New York Tully except the eastern end of the lower member which is quartz sandstone. In terms of percent insoluble content, Pennsylvania limestone layers resemble most closely the transitional beds of the New York Tully and the eastern end of the upper member. Pennsylvania limestones contain an average of 2 to 4 times as much insoluble material as do the central and western parts of both the lower and upper members of the New York Tully. This massive to thick-bedded, relatively pure calcilutite (Plate 1, Figure 3) comprising the majority of the New York Tully was detected nowhere by me in Pennsylvania.

The New York Tully, exclusive of the transitional beds, contains only a minor amount of shale in thin partings whereas at least one-half of the sequences of Pennsylvania Tully at Danville, Lock Haven, and Curtin is composed of shale interbeds which were not included in the values in Table 2. This consideration rectifies the impression given by the low percentage of insoluble mud from point-count analysis (Table 1) of calcilutite of the platy facies and emphasizes the greater overall abundance of noncarbonate terrigenous material in the Pennsylvania Tully. Table 3 illustrates this point. Part A compares the amount of "pure" limestone, defined as containing less than 15 percent insoluble material, present in the Tully limestone in New York and Pennsylvania; part B compares the amount of "limestone", arbitrarily defined as containing less than 50 percent insoluble material and roughly corresponding to what would be termed limestone in the field, in the two major regions of outcrop. The Tully Limestone in Pennsylvania contains practically no "pure" limestone which predominates in New York. Comparison of "impure" limestone to shale ratios illustrates again that the Pennsylvania Tully resembles only the transitional beds and the eastern end of the main part of the upper Tully in New York in terms of composition as well as field appearance.

Table 3.—*Comparison of estimated percentage of limestone of various purity in Tully Limestone in New York (by region and member) and Pennsylvania (by measured section). Estimates made from observation of percent insoluble content values plotted on measured sections.*

a.—Percentage of "pure" limestone containing less than 15 percent acid-insoluble material.

NEW YORK

	West	*Central*	*East*
Transitional beds	0	5	0
Upper Member*	92	90	18
Lower Member	100	67	2

PENNSYLVANIA

Southwest		*East*	
Newry	Curtin	Lock Haven	Danville
0	0	15	0

b.—Percentage of all limestone containing less than 50 percent acid-insoluble material.

NEW YORK

	West	*Central*	*East*
Transitional beds	50	60	50
Upper Member*	100	100	85
Lower Member	100	95	30

PENNSYLVANIA

Southwest		*East*	
Newry	Curtin	Lock Haven	Danville
30**	50***	50	15

The directional trend of eastwardly increasing insoluble material within the Tully Limestone in New York is the result of an eastern clastic source in the Catskill region. A trend is also apparent within the Tully Limestone in Pennsylvania in that insoluble material increases to the southwest and to the east, away from the central region of outcrop. Thus, both the majority of limestone and the purest limestone layers in Pennsylvania occur in that region of outcrop closest to the western and central outcrop in New York where the purest limestones in the entire formation occur.

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* Exclusive of transitional beds

** Field appearance is about 60 percent, but 2 of 4 limestone samples analyzed contain more than 50 percent insoluble material

*** Estimate on well-exposed middle part only

DEPOSITIONAL ENVIRONMENT

The widespread diverse fauna indicates that both knobbly limestone and calcareous shale in the upper part of the Tully Limestone in Pennsylvania were deposited under normal marine conditions. The lower part, particularly the platy limestone containing only a few styliolines, however, may represent some sort of restriction of environment. Shaly calcilutites and calcareous shale comprising the Tully were originally fine sediments of lime, clay, and quartz. Very little coarse carbonate or coarse terrigenous material of detrital origin was supplied to this region. The deposition of a large amount of fine sediment signifies a quiet environment over a large area. Local occurrence of intraclasts in the knobbly limestone facies indicates that shallow water and occasional turbulence were established for a time towards the southwest.

If the southwestern area represents a shelf with a thin veneer of sediment contemporaneous with the thick section of platy limestone at Lock Haven, then this much greater thickness of barren lime and terrigenous muds was deposited in a small local basin. Rapid filling of such a basin with seasonal or climatic control of composition of mud influx would give rise to the rhythmic alternation of rock type observed in the platy limestone facies; seasonal rains on nearby land is the sort of control that would provide periodic fluctuation in influx of terrigenous mud. Groove-cast structures noted by D. L. Woodrow (personal communication, 1965) on the base of several limestone layers suggest rapid deposition on a slope. Rapid deposition in a deeper basin might hinder development of large populations of organisms except for a few soft-bodied burrowers and the probably pelagic styliolines.

Such a localized basin in Pennsylvania reflects its closer position to Appalachian tectonics represented in the “Folded Belt” which may already have been active at this time in the Devonian. Peculiar to any such tectonic activity in central Pennsylvania during the deposition of the Tully, however, is the lack of coarse terrigenous sediments.

In both outcrop regions trends of increasing shale and sandstone point to sources of terrigenous detritus (Figure 4). The Tully Limestone grades into shale to the east, southeast, and southwest in Pennsylvania; northeastward, the shale grades into sandstone. In New York, the Tully Limestone grades eastward into sandstone. Thus a major source of quartz sand is indicated in southeastern New York, and finer clastics dominated the influx from southeastern and southern Pennsylvania.

SOURCE OF LIME MUD

An allochthonous origin is indicated for the lime mud that composes so much of the Tully Limestone in both areas of outcrop. Grabau (1917)

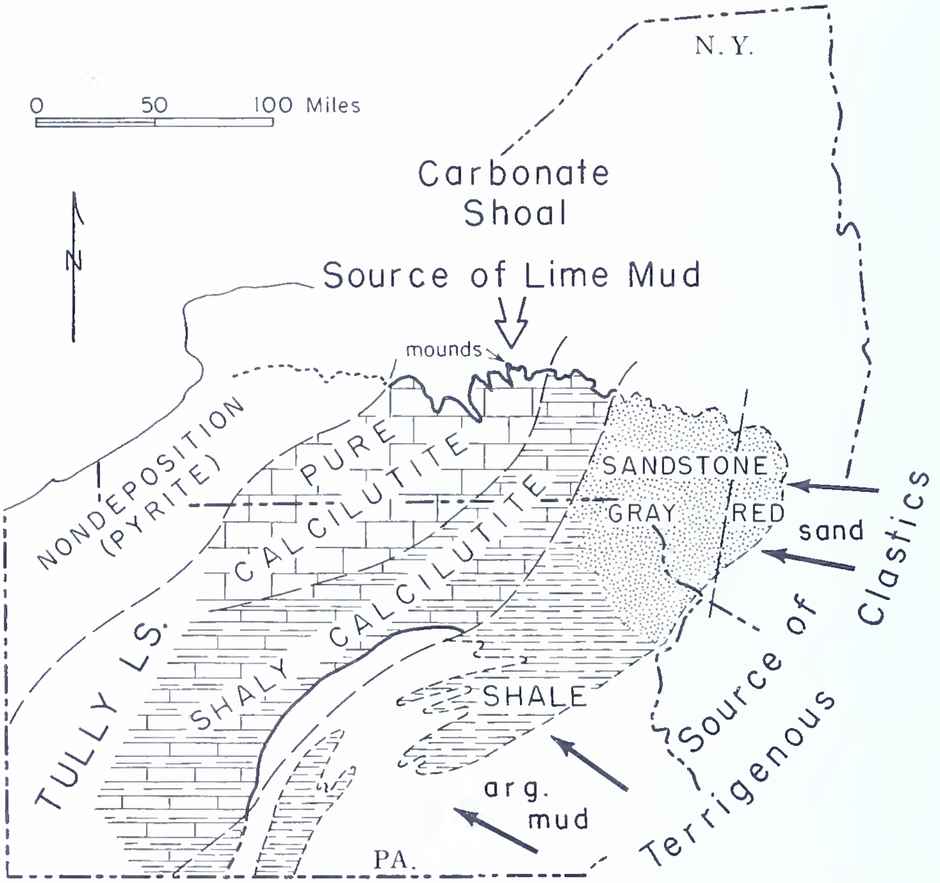

Figure 4. Simplified facies map of Tully Limestone and detrital equivalents in New York and Pennsylvania showing sources of carbonate and terrigenous clastic sediments. Outcrop symbols same as on Figure 1.

was first to note that the fossils in Tully calcilutite in New York are whole and show no signs of abrasion, and thus could not have contributed much lime mud to the environment. Disintegration of green algae upon death releases algal needles to the mud fraction of the sediment (Lowenstam, 1955) but no direct evidence of any sort of algae has yet been observed in the Tully. Furthermore, the unidirectional trend of lime-mud distribution suggests a single source outside rather than local sources within the present area of preserved Tully rocks.

Grabau also recognized the eastern clastic source in the Tully and the western region of nondeposition represented by the Leicester Pyrite. Unaware of the existence of Tully Limestone in Pennsylvania, he postulated that the lime mud originated from the north in an algal or coral reef now completely removed by erosion. Although discovery of Tully Limestone in Pennsylvania may have discredited Grabau's view for a while, the nature of Tully Limestone in Pennsylvania is such that Grabau's conclusion remains the most reasonable that can be made.

Comparison of petrography of the Tully Limestone in Pennsylvania and New York strongly indicates a northern source for the lime mud. There is a marked gradient of decreasing abundance of lime mud in the Tully southward from western New York into Pennsylvania (Figure 4). Limestone layers are both less pure and less common in the formation in Pennsylvania than in western and central New York. Lime mud virtually disappears in the Tully interval south of Pennsylvania suggesting a region even farther from its source. Furthermore, the purest calcilutite known in the Tully Limestone, carrying less than 3 percent insoluble material, occurs in the carbonate-mound complex near Borodino in one of the northernmost exposures of the New York outcrop.

The two different sources for the two types of mud gave rise to the regional pattern of calcilutite and shale distribution shown in Figure 4. Despite this distinct pattern, the environment represented by at least the upper part of the Tully was uniformly one of mud deposition in which the fauna did not react differently to various mineralogic compositions of the mud. This is illustrated by the exposure at Newry where knobbly limestone that contains greater than 50 percent insoluble material (Plate 1, Figure 7) and is thus technically calcareous shale, carries the same fauna and sedimentary structures, and closely resembles calcilutite with less than 15 percent insoluble material in New York. In Pennsylvania, the role of the lime-mud source was decreased relative to that of the terrigenous-mud source, but the same environment with respect to fauna, sedimentary structure, and grain size occurred throughout most of the region of presently exposed Tully Limestone.

Analogy to modern carbonate environment may assist in interpreting the nature of the northern lime-mud source. Rather than the simple algal or coral reef implied by Grabau, it was more likely a broad shoal upon which carbonate-secreting organisms proliferated, and provided the raw material for production of lime mud. Carbonate skeletons are transformed into lime mud through various disintegrational agencies such as mechanical abrasion by currents, loss of binding organic material, and boring, predation, and scavenging by organisms as outlined by Purdy (1963, p. 485-492) in recent carbonates of the Bahamas.

The pure calcilutite mounds at Borodino in New York are structures exhibiting the greatest difference from the remainder of the Tully Limestone preserved today and may have been lime-mud bars extending southward from this organic shoal. The great majority of preserved Tully in New York and Pennsylvania is merely the result of southward current-controlled drift of lime mud farther off the shoal beyond these barlike mounds. The major variation in composition of the preserved Tully was provided by the eastern influx of terrigenous argillaceous mud and quartz sand.

CONCLUSIONS

1. The Tully Limestone in Pennsylvania consists of three facies recognizable in the field rather than two "phases" recognized by Willard (1937). Platy limestone with interbedded shale comprises the lower part of the thicker sections in the central region. Knobbly limestone with interbedded shale comprises the entire thinner Tully to the southwest and the upper part in the central region. Calcareous shale comprises the entire Tully toward the east and interfingers with the knobbly facies in the upper part toward the west.
2. Two faunal assemblages are apparent in the Tully Limestone of Pennsylvania. One assemblage dominated by the brachiopods *Chonetes aurora* (Hall), *Emmanuella pennsylvanica* Willard and *Echinocoelia ambocoeloides* Cooper and Williams occurs in lower knobbly limestone toward the southwest. The more diverse assemblage characterized by small horn and auloporid corals, pelmatozoans, trilobites, styliolines and several genera of brachiopods and bryozoans occurs throughout the upper part of the Tully in knobbly limestone and calcareous shale. Platy limestone and calcareous shale in the lower part of the Tully toward the east are essentially barren of fossils other than styliolines.
3. Correlation by means of a datum based on the first appearance of horn corals divides the Tully Limestone in Pennsylvania into two convenient faunal units corresponding to the lower and upper faunal assemblages. Because of similarity of faunal succession in New York, the lower and upper parts of the Pennsylvania Tully may be correlated to the lower and upper members of the type Tully Limestone in New York.
4. All limestone studied from the Pennsylvania Tully is calcilutite. Knobbly facies calcilutite contains more skeletal material and acid-insoluble mud than platy facies calcilutite. Except for insoluble mud, the average constituent composition and relative abundance of grain types of all Pennsylvania calcilutite is similar to that of calcilutite in the New York Tully.
5. Acid-insoluble residues in the Tully Limestone in Pennsylvania consist primarily of noncarbonate (insoluble) mud which is argillaceous material and fine quartz silt less than .01 mm in grain size; few quartz grains exceed .06 mm in size. This material is similar to that in the upper member in New York but not the lower member which contains a greater amount of coarser silt- and sand-size quartz.
6. Calcilutite of the Pennsylvania Tully contains a much higher content of insoluble residue, with an average of 30 percent, than does the

central and western development of the New York Tully with an average of 8 percent insoluble content. Calcareous shale is minor in occurrence in the New York Tully, but composes at least half of the Pennsylvania Tully.

7. Lime, quartz, and clay mud deposited in a quiet marine environment produced the Tully in Pennsylvania. The knobbly limestone facies probably was deposited in shallower water whereas the platy limestone facies was deposited more rapidly in a local tectonic basin to which there was periodic control of composition of mud influx.
8. The fauna of the upper assemblage did not distinguish mud composition in its environment and is found in fine-grained rock ranging from relatively pure calcilutite in central and western New York to shaly calcilutite and calcareous shale in Pennsylvania.
9. Sources of terrigenous sediment were to the east and southeast. Quartz sand was contributed to the Tully Limestone primarily from southeastern New York, and predominantly finer terrigenous material came from southeastern Pennsylvania.
10. The lime mud composing most of the Tully is allochthonous. Its trend of decreasing abundance southward from New York into Pennsylvania indicates a source north of the New York outcrop as previously suggested by Grabau (1917). This source was probably a reefy shoal upon which proliferating skeleton-bearing organisms underwent various modes of disintegration to produce lime mud. This mud was swept by currents southward across central-western New York to form the calcilutite of the presently preserved Tully Limestone. Farther southward, lime mud was increasingly intermixed with terrigenous mud from the east and southeast to form the shaly calcilutite and calcareous shale of the Tully Limestone in Pennsylvania.

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APPENDICES

A. LIST OF LOCALITIES USED IN MAKING TULLY CROSS SECTION IN PENNSYLVANIA (FIGURE 3), WITH 15-MINUTE QUADRANGLES IN WHICH THEY ARE LOCATED.

Hollidaysburg quadrangle

- N New roadcut in U. S. Rte. 220, about 1 mile south of Newry, Blair County.

Centre Hall quadrangle (NW Corner)

- C Exposure along northeast side of bend in Bald Eagle Creek, about 1 mile northeast of Curtin, Centre County.

Lock Haven quadrangle

- LH Roadcut at Lockport just across Susquehanna River from Lock Haven, Clinton County.

Shamokin quadrangle

- D Roadcut along Pa. Rte. 45, about 1 mile south of Danville, in Northumberland County.

Mauch Chunk quadrangle

- B New roadcut along Pa. Rte. 45, on east side of Lehigh River a little north of Bowmanstown, Carbon County. (This is eastern equivalent shale.)

B. PETROGRAPHIC METHODS

Point count: For each thin section, the grain type at 500 points on a predisposed grid was tabulated under a petrographic microscope, and percentage composition was computed.

Determination of composition of mud: Because carbonate mud and acid-insoluble (noncarbonate or terrigenous) mud cannot be distinguished from one another under the petrographic microscope, all mud less than .01 mm in grain size was tabulated as a single category in the point count. Percentage of acid-insoluble mud was determined by subtraction of acid-insoluble grain types $>$ .01 mm, such as quartz and pyrite, from the total insoluble residue of the slab adjacent to that thin sectioned in each sample; the remainder is insoluble mud $<$ .01 mm. This value subtracted from total mud $<$ .01 mm leaves soluble (carbonate) mud $<$ .01 mm. For Table 1, a separate category of carbonate silt (.01 mm to .062 mm) was added in order to arrive at carbonate mud $<$ .062 mm.

Insoluble residue: Slabbed sample weighing between 20 to 40 g was weighed to the nearest 0.1 g, and dissolved in a solution of 1 part formic acid to 5 parts water. The resulting residue was washed, weighed, and the coarser fraction examined under a binocular microscope with a graded ocular.

C. POINT-COUNT DATA, AVERAGED IN TABLE 1, FOR INDIVIDUAL THIN SECTIONS FROM LIMESTONE IN PENNSYLVANIA

Locality Facies Position	*Newry* *knobbly* *base*	*Newry* *knobbly* *lower middle*	*Newry* *knobbly* *upper middle*	*Curtin* *knobbly* *lower*	*Curtin* *knobbly* *middle*	*Lock Haven* *platy* *base*	*Lock Haven* *platy* *lower*	*Lock Haven* *platy* *middle*
Corals	....	3.4	....	....	2.8	....	....	.
Bryozoans	....	...			2.0	....	....	....
Brachiopods	2.2	0.2	0.6	0.2	3.0	....	....	
Molluscs, etc.	....	...		.	....	....	....	....
Trilobites	...	0.6	1.2	....	1.4	....	..	
Echinoderms	0.2	5.6	14.6	....	4.4	0.2	....	....
Styliolines	1.4	16.4	4.0	1.6	1.2	2.2	0.4	2.6
Unknown skeletal sand	3.4	5.0	4.8	1.0	2.4	6.2	....	0.6
Total skeletal	7.2	31.2	25.2	2.8	17.2	8.6	0.4	3.2
Carbonate mud < .062 mm	67.1	9.8	37.9	72.7	57.8	66.4	86.1	78.4
Carbonate spar	....	0.6	0.4	....	1.6	....	0.6	..
Insoluble mud < .01 mm	23.9	54.0	36.1	22.7	22.8	21.0	10.1	12.0
Quartz, other detrital > .01 mm	..	3.6	0.4	1.0	0.4	3.2	2.2	5.6
Other noncarbonate	1.8	0.8	....	0.8	0.2	0.8	0.6	0.8
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

D. PERCENTAGE INSOLUBLE RESIDUE OF INDIVIDUAL SAMPLES OF TULLY LIMESTONE AND DETRITAL EQUIVALENT IN PENNSYLVANIA LISTED IN VERTICAL ORDER BY MEASURED SECTION. SH REPRESENTS CALCAREOUS SHALE WITHIN THE TULLY WHICH IS NOT INCLUDED IN TABLE 2. ALL VALUES ARE ROUNDED OFF TO NEAREST UNIT.

Newry	Curtin	Lock Haven	Danville	Bowmanstown
59	23	18	50	99 sh
37	85 sh	36 sh	85 sh	92 sh
58	25	73 sh	44	99 sh
26	32	23	32	100 sh
		13	57 sh	
		25		

Plate 1.—Photographs of Tully Limestone outcrop in Pennsylvania and New York and thin section photographs of Tully Limestone in Pennsylvania. Bar in lower left of thin section photographs is 1 mm long.

Figure 1.—Lower part of Tully Limestone at Lock Haven, Pennsylvania, showing thin-bedded, rhythmic alternation of limestone and shale typical of the platy limestone facies. Head of jacob staff in lower center is 10.5 inches long.

Figure 2.—Upper part of Tully Limestone at Lock Haven, Pennsylvania, showing calcareous shale so common in Pennsylvania Tully separating layers of shaly limestone belonging to knobbly facies. Macrofossils occur only in this part of the Lock Haven section.

Figure 3.—Tully Limestone, excluding transitional beds, at Moravia, New York, showing thick-bedded limestone composed of relatively pure calcilutite that is typical of both members of the Tully Limestone in central and western New York. Compare to shaly nature of Pennsylvania Tully illustrated above. Jacob staff in lower right is 4 feet long.

Figure 4.—Thin section from lower part of Tully Limestone at Lock Haven, Pennsylvania, showing calcilutite typical of the platy facies. Only scattered styliolines and a trilobite fragment are seen. Other thin sections from this facies contain even less identifiable skeletal material. Slight mottling probably records burrowing.

Figure 5.—Thin section from middle of Tully Limestone at Curtin, Pennsylvania, showing skeletal calcilutite typical of the *Atrypa-Phacops* zone of the upper faunal assemblage in the knobbly facies. Fossils include *Atrypa spinosa*, echinoderm and trilobite pieces, and bryozoans.

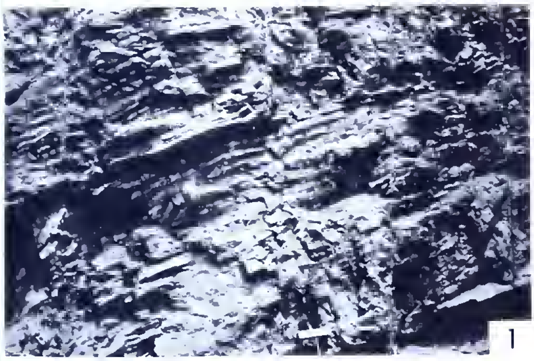
Figure 6.—Thin section from upper middle of Tully Limestone at Newry, Pennsylvania, showing intraclasts locally present in skeletal calcilutite of the knobbly facies. Upper faunal assemblage fossils include echinoderm and trilobite pieces, and abundant styliolines.

Figure 7.—Thin section from lower middle of Tully Limestone at Newry, Pennsylvania, showing shaly calcilutite common in the knobbly facies. This sample contains over 50 percent acid-insoluble terrigenous mud, hence was easily scratched during grinding. Fossils include small horn coral *Syringaxon*, characterizing upper faunal assemblage, echinoderm pieces and crushed stylioline debris.

Figure 8.—Thin section from base of Tully Limestone at Newry, Pennsylvania, showing brachiopods typical of the lower faunal assemblage in the knobbly facies. Fossils include probable *Emmanuella*, highly bored, in upper right, *Chonetes aurora* (small) and possible *Echinocoelia* (large) in lower left, and scattered styliolines. Pyrite in center.

PENNSYLVANIA GEOLOGICAL SURVEY

PLATE 1, IC 60



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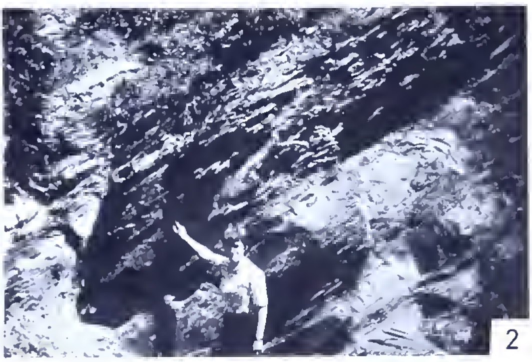

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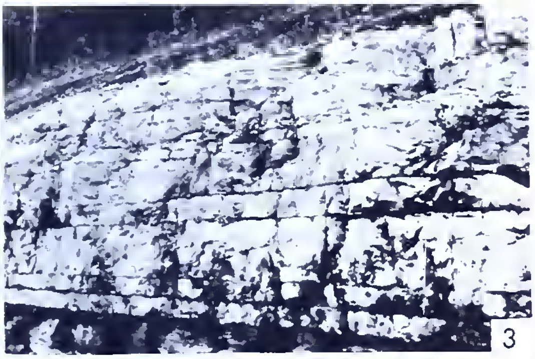

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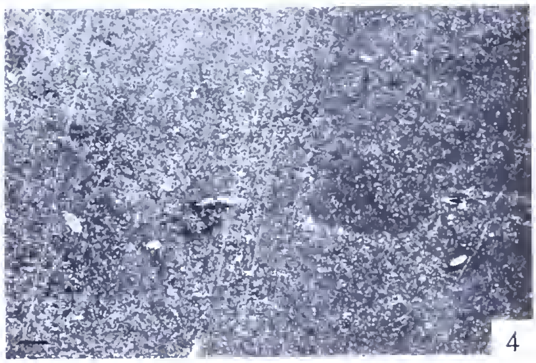

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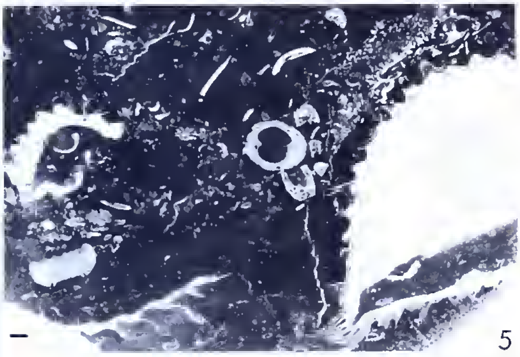

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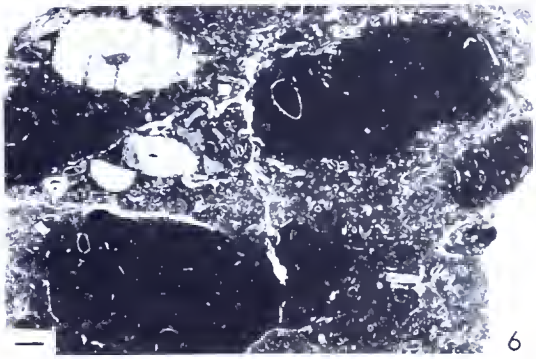

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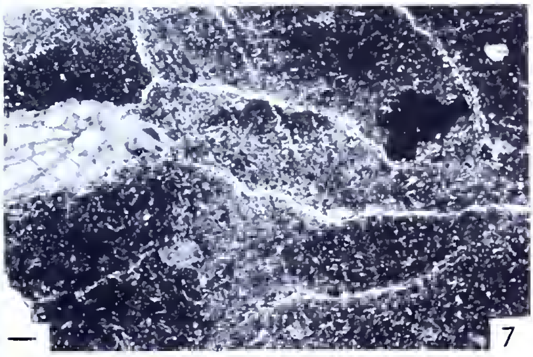

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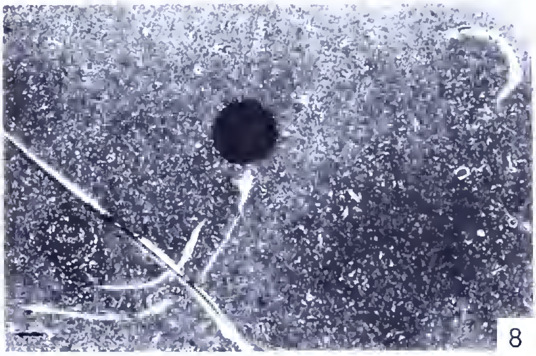

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